Looking forward: In-vehicle auxiliary display positioning affects carsickness

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Title:

Looking forward: in-vehicle auxiliary display positioning affects carsickness

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Abstract:

Carsickness is associated with a mismatch between actual and anticipated sensory signals. Occupants of automated vehicles, especially when using a display, are at higher risk of becoming carsick than drivers of conventional vehicles. This study aimed to evaluate the impact of positioning of in-vehicle displays, and subsequent available peripheral vision, on carsickness of passengers. We hypothesized that increased peripheral vision during display use would reduce carsickness. Seated in the front passenger seat 18 participants were driven a 15-minute long slalom on two occasions while performing a continuous visual search-task. The display was positioned either at 1) eye-height in front of the windscreen, allowing peripheral view on the outside world, and 2) the height of the glove compartment, allowing only limited view on the outside world. Motion sickness was reported at 1-minute intervals. Using a display at windscreen height resulted in less carsickness compared to a display at glove compartment height.

Keywords: motion sickness, displays, autonomous vehicles

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1. Introduction

1.1

Motion sickness can be defined as a state of discomfort caused by real or apparent motion (Reason and Brand, 1975). Signs and symptoms of motion sickness are initially, among other things, (cold)

sweating, pallor, burping, salivation, apathy, that may subsequently be followed by nausea, retching and finally vomiting. The occurrence and degree of these symptoms may vary considerably between people, however everyone with a functional vestibular system appears susceptible to motion sickness to some extent (Money, 1970). The underlying mechanism of motion sickness has been theorized to be a mismatch between actual and anticipated sensory signals, typically modulated through visual-vestibular conflicts (Bles et al., 1998; Bos et al., 2008). Alternatively, motion sickness has been proposed to result from postural instability, stemming from sensory information incongruent with how balance is maintained in a natural or known environment (Riccio and Stoffregen, 1991). Therefore, under either theory, *in*congruences in what is seen and (normally) experienced through other senses, such as when below deck at sea, or when reading a book in a car, can *aggravate* motion sickness. Conversely, congruent sensory information, e.g. looking at the earth-fixed horizon when on a moving ship, *alleviates* motion sickness, even when this is presented artificially (Bos et al., 2008; Feenstra et al., 2011; Tal et al., 2012).

1.2

Carsickness is a form of motion sickness of which two-thirds of all people have suffered from at some point in their life (Reason and Brand, 1975). Passengers in particular, rather than drivers, become motion sick, even when exposed to identical motion (Rolnick and Lubow, 1991; Dong et al., 2011; Chen et al., 2012). One reason for this is that when controlling a vehicle, motion can correctly be anticipated, reducing the discrepancy between sensed and expected motion. Another, related, reason for the increased risk of motion sickness of passengers is the fact that passengers are not required to have a view out-the-window to operate the vehicle. Restricted vision of the outside world was found to aggravate carsickness (Griffin and Newman, 2004). As opposed to the world outside the vehicle, the vehicle interior moves in conjunction with its occupant, increasing sensory incongruences as more of the visual field is occupied by the vehicle interior. The beneficial effect on motion sickness of out-the-window view holds was found to hold true for both central and peripheral vision independently.

1.3

Autonomous vehicles, or rather *highly automated vehicles* (Reilhac et al., 2016), are expected to replace conventional vehicles in the coming decades (see e.g. Litman, 2014). Potential benefits of these future self-driving vehicles are safer roads, reduced traffic congestion, increased fuel efficiency, and time saved by the possibility to engage in non-driving activities (Begg, 2014). However, extensive adoption of self-driving vehicles could lead to increased motion sickness in the general population. Currently, over three quarters of commuters in the US are the sole occupant of their vehicle when getting to work (McKenzie, 2015). This population of drivers will become passengers once automated vehicles are widely adopted. As mentioned, passengers have an increased risk of motion sickness compared to drivers. In addition to this, a key benefit of automated vehicles, i.e. engagement in non-driving activities, may further inhibit passengers' out-the-window view. This, in turn, exacerbates the visual-vestibular mismatch believed to underlie carsickness. However, concept car designs often show sizable, possibly even head mounted, displays to be used for work or entertainment. If engagement in such in-vehicle displays becomes the default state of the occupants of future vehicles, preventing carsickness is expected to become a considerable challenge for vehicle manufacturers. Consequently, display positioning could become a potentially important factor modulating motion sickness in future automated vehicles through influencing available peripheral out-the-window view.

1.4

In the present study we therefore aimed to investigate the effect of display positioning on motion sickness in car passengers using an in-vehicle display. We elaborated on an exploratory on-road study (Diels et al., 2016) which included a head-up versus head-down display position. Findings suggested that a head-up display may be able to reduce motion sickness. However, the study suffered from several confounding factors, most crucially the variability in vehicle motions due to the experiment taking place in traffic. For the current study we realized an experiment with reproducible vehicle motion and an hypothesis based on a within-subjects design with two conditions manipulating display position. In one condition the display was at windscreen height (HIGH), and in the other condition at glove compartment height (LOW), the latter offering only limited peripheral vision. The hypothesis tested was that the condition which allowed for more optimal peripheral vision, thus minimal visual-vestibular incongruences, would result in the least motion sickness. To be able to better interpret the main analysis concerning the effect on motion sickness between the two conditions, motion sickness across participants was also analysed both in proportional terms, and in terms of difference in increase in illness over time.

2. Methods

2.1 *Motion stimulus and test environment*

2.1.1

The study was undertaken using a typical medium-sized estate car (Volkswagen Passat). The vehicle was equipped with an automatic gearbox and cruise control. An accelerometer (Xsens Technologies B.V.) was mounted on the floor of the vehicle behind the front seats. An on-board computer recorded the motion sensor data in conjunction with controlling the task.

2.1.2

For controllability and safety reasons the experiment was realised on a privately owned tarmac road approximately 600 m long, without any other traffic present. Slaloms were driven around markers on the centre of the road 20 m apart, resulting in 13 40 m cycles on the 600 m long track. Each slalom manoeuvre was followed by a U-turn at the end of the track immediately followed by another slalom (see figure 1). Each slalom was driven at a constant speed of 25 km/h using the vehicle's cruise control.

2.1.3

Following a pilot study exploring the effectiveness of different slalom profiles, we found that a distance of 1 m between the vehicle and the markers at the peak of each lateral motion resulted in a stimulus that was provocative yet not leading to vomiting in a short period of time. As a result, each slalom had an amplitude of 1.5 m and a frequency of 0.16Hz. This frequency in particular has been shown to be most provocative for motion sickness (O'Hanlon and McCauley, 1973). These slaloms were repeated 8 times, lasting 15 minutes in total, including the U-turns. There were two drivers, both of whom had practised driving the slalom at the test track beforehand. Participants were assigned to only a single driver to control for any variation between drivers.

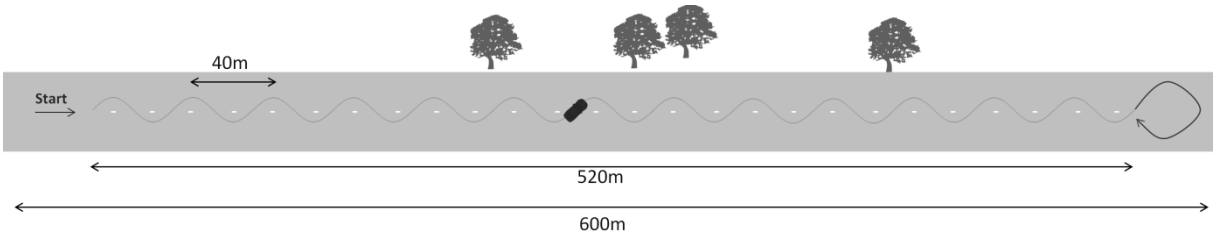

Fig 1. [two columns] Schematic of the test track. The vehicle was driven around 26 markings in slalom driving, corresponding to 13 cycles of 40m. At the ends of the test track there was ample room to do a controlled U-turn. The amplitude of each slalom was 1.5m measured from the markings to the centre of the car. The maximum angle of yaw as seen from the centre-line was about 20°.

2.2. Experimental conditions

2.2.1

Two display conditions were realised in otherwise identical circumstances. In the HIGH condition, the display was positioned at eye-height in front of the windscreen, providing considerable peripheral out-the-window view. In the LOW condition, the display was positioned at the height of the glove compartment, offering considerably less view on the outside world as compared to the HIGH condition. The display was pitched to ensure that the viewing angle was equal in both conditions. The seat could be raised vertically to compensate for participant height, keeping the display at eye-height.

2.3 In-vehicle display and task

2.3.1

The task was presented on a tablet with an 18 cm (7 inch) screen diameter mounted to the dashboard by the passenger seat in the two possible configurations (see figure 2). The distance to the screen was 60cm, resulting in a FOV of about 15°. The task required constant visual attention, preventing participants from taking their eyes off the display and thus influencing their available peripheral vision. The task itself was an adaptation of the SuRT task (SuRT, ISO14198, 2012) and consisted of a continuous series of trials over the entirety of each of the 15-minute conditions. In every trial a static grid of 36 arrows was presented with arrows pointing down, left, or right. In half of the trials a single arrow pointing up was present. The participant was instructed to push a ‘yes’ button on a hand-held box when an up-arrow was identified, and a ‘no’ button when the upward pointing arrow was absent. After responding, the next grid was immediately displayed regardless of response given, to keep the participant engaged. If within 3 seconds no button was pressed, a fixation cross was presented for 1s to indicate a miss, immediately followed again by the next trial. No other feedback on task performance was given. Participants were instructed to keep their visual attention on the task throughout the experiment and to keep their head in approximately the same position (i.e. “don’t make large adjustments in posture during the experiment”).

Fig. 2 [two columns] The two variations of display positioning used in this experiment, HIGH (left) and LOW (right).

2.4 Motion sickness measures

2.4.1

During each 15-min condition, participants provided self-ratings of their motion sickness severity at 1-min intervals as indicated by an auditory beep, using an 11-point misery scale (MISC, table 1, Bos et al., 2005). The scale exploits the knowledge that all motion sickness symptoms other than nausea, retching and vomiting may vary between participants, but, if present, these symptoms normally precede the latter. A MISC of 6 or higher (i.e., any nausea), was taken as a criterion to terminate a running condition so as to allow participants to recover in between conditions and minimising cross-over effects. If a condition had to be stopped due to nausea, the last reported MISC rating was conservatively assumed for the remaining measuring moments, thus preventing missing values and facilitating the statistical analysis.

Table 1.
11-point MIsery SCale (MISC) (Bos et al., 2005)

Symptoms		Misc
No problems		0
Some discomfort, but no specific symptoms		1
Dizziness, cold/warm, headache, stomach/throat awareness, sweating, blurred vision, yawning, burping, tiredness, salivation, . . . but no nausea	Vague Little Rather Severe	2 3 4 5
Nausea	slight fairly severe (near) retching	6 7 8 9
Vomiting		10

2.5 Procedure and Participants

2.5.1

Approval by the TNO Human Factors institutional Review Board on Experiments with Human Subjects was obtained in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Candidate participants which indicated they had never suffered from motion sickness in any mode of transport for the last five years were not considered for this experiment. All participants included were free of vestibular disorders as known by themselves, and had not been drinking alcoholic beverages during 24 hours in advance of the experiment. Also they were informed about the purpose and procedures of the experiment and signed an informed consent prior to the first experimental condition. A total of 18 participants, 8 males and 10 females, participated in this study. Ages ranged from 19 to 33 years with an average of 26 ± 4.6. Participants alternated in couples with respect to the two conditions realised, allowing them a pause in between the two conditions of approximately one hour. Prior to the experiment the MISC-scale was explained to the participant in conjunction with the task instructions, and then again at the start of each condition to ensure retention. The experimenter controlled the vehicle while the participant took place on the passenger seat with the display in front of them. Anticipating the first condition, participants practiced the task until it was clearly understood. Before each condition, participants reported their initial MISC. An MISC of 2 or up (i.e. any symptoms) at the start of a condition was considered undesirable and would therefore lead to exclusion. The conditions were counterbalanced between participants to prevent order effects.

2.6 Statistical methods

2.6.1

To quantify the variability in slaloms driven, a power spectral density analysis was performed on the lateral acceleration data, yielding both peak frequency and RMS acceleration amplitude. Paired t-tests were used for accelerometer data and task scores. Parametric repeated measures ANOVA was used with MISC ratings as the dependent variable. Three factors were included: condition, time and participant. Participant was included as a random factor. To visualize inter-individual differences we used linear regression slopes for each participant per each condition, and compared these with a paired t-test. Statistical data analysis was performed using R (Version 3.3.1). Averages are reported along with their standard deviations. Due to incidental conditions, among which an initial MISC ≥ 2, data from three participants were excluded. Data analysis was subsequently performed on data from 15 participants.

3. Results

3.1 Motion profiles

3.3.1

A power spectral density analysis of the lateral acceleration sensor data revealed an average peak slalom frequency of 0.161 Hz ± 0.01. Therefore, the frequency variability between conditions and participants was about 6%. There was no significant difference between the two conditions in terms of peak frequency ($t(24) = 0.547$, $p = 0.590$). Average RMS of lateral acceleration was 1.12 m/s^2 ± 0.14, meaning the amplitude variability across all participants and conditions was about 13%. The RMS of lateral acceleration did not significantly differ either between conditions ($t(24) = 0.431$, $p = 0.670$).

3.2 Motion sickness scores

3.2.1

The average illness rating after 15 minutes was 2.0 ± 2.10 in the HIGH-display condition, and 2.8 ±1.81 in the LOW-display condition. This corresponds to a 43% reduction of illness scores. Figure 3 shows the illness ratings of participants for the two conditions over the entire 15-minute period. A repeated measures ANOVA showed a significant increase in score over time for both conditions ($F(1,14) = 32.69$, $p < 0.001$, partial $\eta^2 = 0.578$). A significant effect of condition on illness scores was also found ($F(1,14) = 5.012$, $p = 0.042$, partial $\eta^2 = 0.264$). Regression lines (as also shown in figure 3) were derived from the LOW ($F(1,238) = 67.580$, adjusted $R^2 = 0.218$, $p < 0.001$) and the HIGH ($F(1,238) = 55.499$, adjusted $R^2 = 0.186$, $p < 0.001$) subsets of the data. These regression lines also significantly differed, $F(1,476) = 8.164$, $p = 0.004$. This was analysed by using a dummy variable for the HIGH/LOW conditions, and examining the interaction effects of the linear model.

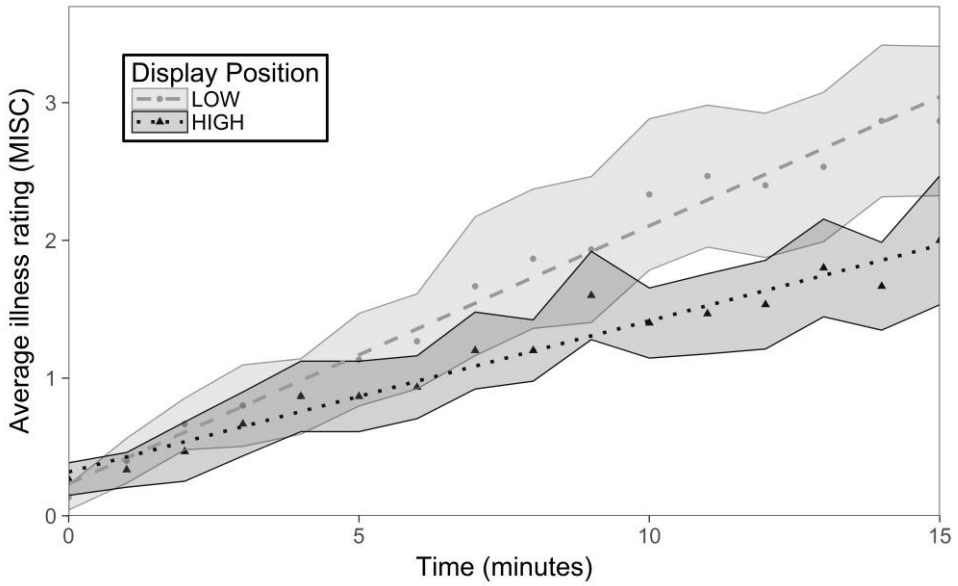

Fig 3. [two columns] Average illness ratings over time for the LOW and the HIGH condition. Grey areas depict SEM.

3.2.2

An alternative way to explore the data, rather than examining average scores, is to look at the percentage of participants over time that reached certain thresholds of illness rating (MISC). In motion sickness studies, often a portion of participants show no effect to the provocative stimulus (see e.g. Dong et al., Perrin et al, 2013; . This can be seen in figure 4. Each line represents the proportion of participants that reached a certain illness rating at that time of measurement. Note that a MISC of 1 is "*some discomfort, but no symptoms"*, and was therefore sometimes scored at the beginning of a drive. As can be seen from the top most lines in the graph, the proportion of participants that scored a MISC of at least 1 increased at roughly the same rate in both conditions. However, looking at the development of further symptoms, as can be seen in the lines for the MISC reaching 3 or higher and 5 or higher, the two conditions differ.

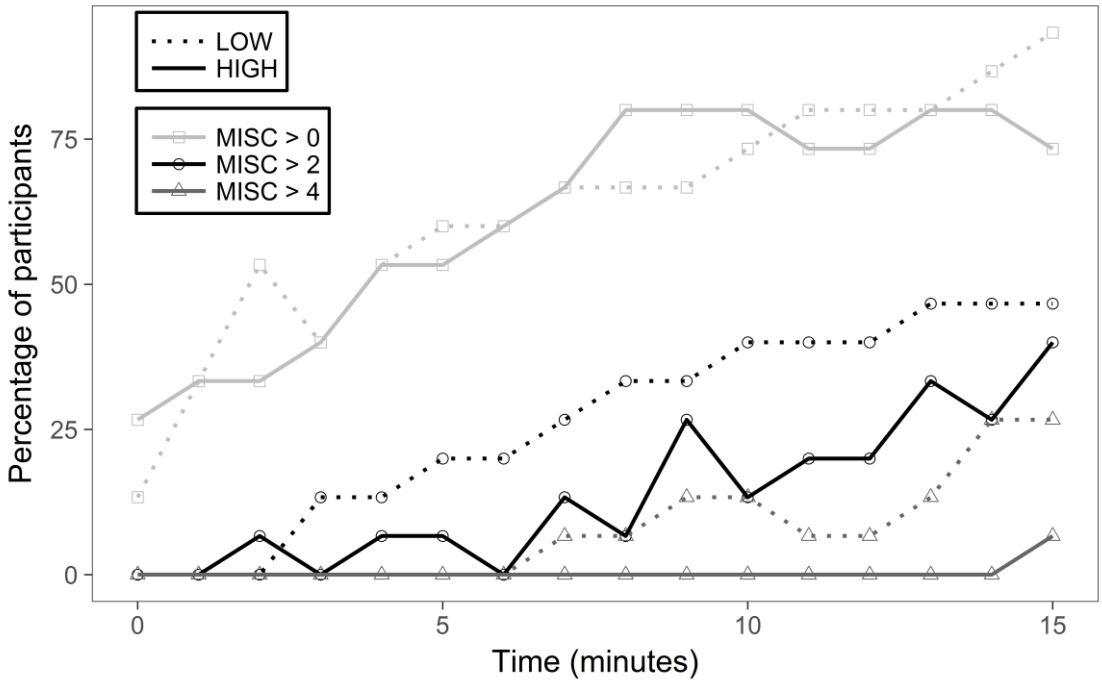

Fig. 4. [two columns] Percentage of participants over time that attain at least a certain illness score (MISC). Both conditions illicit a similar response in terms of initial rise in MISC (the lines using squares). However once this threshold of a MISC of 1 is reached, the LOW condition illicits a larger effect, as indicated by a higher proportion of elevated MISC scores.

3.2.3

To further explore the differences between conditions within participants we used an addition analysis. For each participant two regression lines, one for each condition, were calculated. For each regression line, the intercept was fixed at the initial illness score at t=0. The average adjusted R-squared of the regression lines was 0.776 ± 0.249. The values of the slopes of these regression lines, i.e. the fitted amount of increase in MISC score per each unit of time, are shown in figure 5. A paired t-test showed these regression slope values differ significantly between the HIGH and LOW condition, $t(14) = 2.771$, $p = 0.015$.

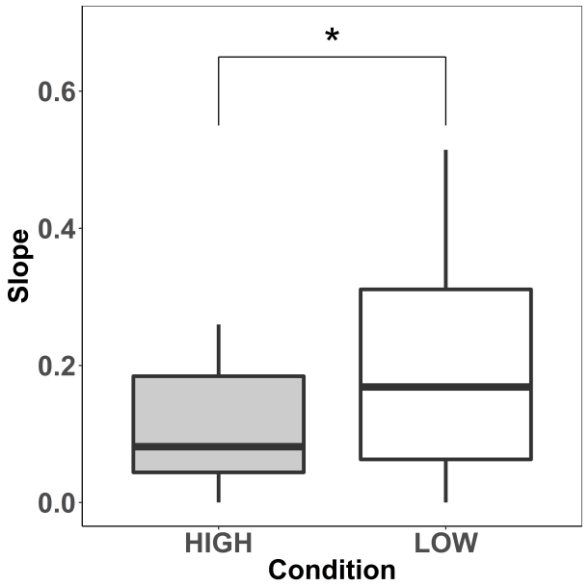

Fig 5. [one column] A regression line for each condition (HIGH/LOW) and each participant was calculated. Boxplots show the slopes of these regression lines.

3.3 Task performance

3.3.1

We analysed task performance to assess whether participants consistently attenuated to the task across the two conditions. On average, participants scored 90.5% (± 5.1%) of the trials on the search task correct, with 9.5% incorrect or late answers. There was no significant difference between the two conditions in terms of task performance (paired t-test t(12) = -0.41494, p = 0.686). Average reaction times were slightly lower for the HIGH condition with 1.25 (± 0.26) seconds on average compared to 1.32 (± 0.24) seconds for the LOW condition. However, this difference was also not significant (paired t-test t(12) = 1.2136, p = 0.248).

4. Discussion

4.1

In this study we examined the level of carsickness in front seat passengers performing a visual search task using a display positioned at 1) eye-height in front of the windscreen (HIGH), providing considerable peripheral out-the-window view, and 2) at the height of the glove compartment (LOW) offering considerably less peripheral vision. In line with the hypothesis that increased peripheral vision reduces carsickness, the HIGH display position was indeed found to lead to significantly less motion sickness compared to the LOW display position.

4.2

Our findings are in line with other studies showing the beneficial effect of enhanced peripheral vision on carsickness. For instance, Probst and colleagues (1982) also found that out-the-window view led to significantly reduced motion sickness compared to viewing an artificial static visual field (a map) located on the passengers' laps. A study by Turner and Griffin (1999) showed a correlation of motion sickness and seating position in coach passengers which was attributed to differences in forward vision

as a function of position. Similarly, Griffin and Newman (2004) showed in multiple experimental conditions that out-the-window view significantly reduces motion sickness, especially when this view contains information about the trajectory of the vehicle. Perrin and colleagues (2013) found that professional rally co-drivers reported increased motion sickness when taking notes during course reconnaissance, reducing out-the-window vision. These studies, expanded upon by our findings of reduced motion sickness with increased peripheral vision, underline the importance of the relationship between vision and carsickness. The findings of Diels and colleagues (2016) found a similar effect as our study, with a head-up display leading to a reduced incidence of motion sickness. Our congruent data substantiates the findings of that exploratory study. In addition, their findings are in support of generalizability of our findings, namely that the effect of display position may hold under car motion in natural traffic rather than only during slalom driving. While the design of this study did not allow to investigate underlying (neural) mechanisms of carsickness, results of the present study reaffirm the importance of vision on carsickness.

4.3

Having a completely unobstructed view on the earth-fixed world around the vehicle is the quintessential way to reduce motion sickness following visual-vestibular incongruences. However, with limited vision, motion cues can still be inferred from both foveal and peripheral vision. While the *peripheral dominance hypothesis* (Dichgans and Brandt, 1978) has been nuanced, peripheral vision is still regarded as being paramount in self-motion perception (Webb and Griffin, 2003; Bardy et al., 1999; Warren and Kurtz, 1992). Self-motion perception is principally related with *vection*, which is the perceived sense of self-movement (Palmisano et al., 2015). It is *vection*, rather than simply optic flow, that is assumed to play a major role in motion sickness in which a visual component is involved (Stern et al., 1990; Keshavarz, et al., 2015). Thus, when central visual information is restricted (e.g. when working on a screen), peripheral vision is a central factor modulating motion sickness mediated through its role in self-motion perception, as also evident in the present study. However, researchers on carsickness should be aware not to fixate on a single aspect, such as peripheral vision, given that nuances in the visual scene during motion -or even optic stimuli by themselves- cause or can modulate motion sickness in a complex and multifaceted fashion (So and Ujike, 2010; Bos et al. 2010; Kennedy et al., 2010).

4.4

A factor that might be thought to have impacted the participants' sickness in this study is the voluntary or inattentive head orientation of participants. Namely, we did not restrain the head of participants, but rather left them free to orient their head in any position. Besides the instruction to try to keep their focus on the display, and not to drastically alter their posture, no other instructions were given. However, the slalom motion we utilized exposed participants predominantly to lateral linear motion, and to our knowledge there is no evidence in the literature which suggests that the otoliths, the vestibular organs sensitive to lateral linear acceleration, function differently under different head orientations. The semi-circular canals, sensitive to angular motion, receive equal stimulation regardless of head tilt. In addition, a study by Wada and Yoshida (2016) found vision is the predominant factor affecting carsickness even with a head tilt of 20° against baseline. Therefore, we do not expect head tilt to have had a large impact on eventual motion sickness compared to the effect of vision.

4.5

In this study, sickness sores after 15 minutes of exposure did not lead to excessively high sickness scores, on average 2.0 and 2.8 for the HIGH and LOW condition, respectively. This was however anticipated. Motion sickness is a process over time, typically increasing monotonically during the first 60 minutes of consistent motion exposure (McCauley et al., 1976). As also evident in our findings, prolonged exposure to motion has an additive effect on the severity of sickness. We selected the motion stimulus with the goal to invoking a response in the majority of participants while preventing unnecessary discomfort. Our data was best modelled by a linear fit, implying prolonged exposure to the stimulus would have led to increasing motion sickness scores and continued differentiation between the two conditions. However, it must be noted that a comprehensive model of motion sickness over time could not be strictly linear, given the upper limit of the scale being a maximum score of 10 (defined as vomiting). However given the present data and the knowledge of the monotonic rise of motion sickness given continuous stimulus, there is good reason to assume average sickness scores would have continued to rise after the 15 minute duration.

4.6

A different factor that may have somewhat dampened our motion sickness levels was participants' continuous engagement in a (mentally) distracting task (i.e. visual search task) which has previously been shown to reduce motion sickness (Bos, 2015). Given the task's demanding nature, requiring continuous attention as substantiated by consistent scores across participants, it most likely diminished overall sickness scores in this experiment. However, since the principal aim in this study was to investigating the effect of peripheral vision, a method demanding continuous visual attention was required to ensure the participants' gaze remained on a display. This necessitated inclusion of the task in our design. Given the confounding nature of the illness reporting procedure, no conclusions concerning the effect of motion sickness on task performance can be drawn. Finally, a factor influencing motion sickness, was that the slalom used for controllability is by definition a predictable motion, which reduces sickness (Rolnick and Lubow, 1991; Dong et al., 2011). This implies that natural vehicle motion of similar intensity rather than a repetitive motion would be expected to result in higher sickness levels.

4.7

Since the inception of automobile travel, the subject of carsickness has received only limited attention among scientists. More surprising is that despite the recent substantial attention for self-driving vehicles, carsickness in automated vehicles has received equally limited attention, although various authors established that carsickness might be a serious issue in self-driving vehicles (Diels, 2014; Diels and Bos, 2015; Sivak and Schoettle, 2015; Diels and Bos, 2016). However, the public's acceptance of automated vehicles, despite the plethora of advantages they offer, might be seriously impeded if carsickness proves to be a serious issue. Concept cars often show designs where emphasis is put on use of in-vehicle displays and the ability to rearrange seats to create a more 'living-room like' experience. However, further reducing external and forward vision of passengers (Griffin and Newman, 2004), such as through backward facing seats or even head mounted displays, will further exacerbate the risks at carsickness. While self-driving vehicles do not need windows to operate, it is imperative to focus on the passengers' comfort experience which suggests that windows are here to stay.

4.8

In addition to comfort, carsickness may also have implications for driver safety. Following the Society for Automotive Engineers taxonomy (SAE, 2014), current production vehicles with e.g. lane-keeping

assistance and adaptive cruise control offer level 2 automation. Full door-to-door automated driving would constitute level 5 automation. In the intermediate phases the vehicle's occupant will be able to engage in other activities but has to be able to take back control of the vehicle in a limited timeframe. This *transfer of control* has already been the focus of several studies concerning envisaged safety risks. Delayed or reduced situation awareness, potential drowsiness, and distraction from engagement in non-driving activities can have a detrimental effect on the ability to operate a vehicle after a period of inactivity (Vlakveld, 2016). Research into transfer of control should include motion sickness as a factor of interest in addition to these factors, since even mild motion sickness is known to reduce task performance (Rolnick and Bles, 1989; Bos, 2004). When passengers with restricted vision in automated vehicles are exposed to provoking vehicle motion (e.g. windy roads, repeated lane changes or inner city traffic), their take over and subsequent driving abilities may be compromised due to motion sickness.

4.9

As stated before, a better view-out-the window reduces carsickness since it provides an earth-fixed reference frame congruent with the vehicle's motion. While non-visual means of counteracting motion sickness (Keshavarz & Hecht, 2014) might be feasible in cars, the effect of vision in carsickness is better understood. Interestingly, the beneficial effect of vision has been shown to be remain when this visual information is presented artificially (Bos et al., 2008; Feenstra et al., 2011; Tal et al., 2012; Kato and Kitazaki 2008; Miksch et al., 2015). For instance, Feenstra and colleagues (2011) showed that the addition of earth-fixed reference points in a flight simulator going through predetermined motions could reduce motion sickness by 50%. Participants in this study were not told about the nature of the earth-fixed reference points, demonstrating that such artificial stimuli can be intuitively beneficially. When adding an anticipatory future motion trajectory the reduction in motion sickness was up to 80%. Utilizing similar artificial presentations of an earth-fixed reference frame and future motion trajectories could provide effective means to reduce carsickness in automated vehicles. However, more research is needed to assess the feasibility of this technology on the road, rather than in a simulator.

4.10

This paper aimed to reaffirm the general importance of vision on carsickness, and specifically to quantify the effect of display positioning on carsickness. The results found here aid in further understanding the functional role of peripheral vision out-the-window in carsickness. Additionally, this study contributes practical knowledge that can be used in automotive design to increase passenger comfort by offering an elementary guideline for display positioning. Looking forward into the future, passengers of self-driving vehicles will expectedly be exposed to a vastly different visual scene than occupants of vehicles today, with engagement in displays being a central aspect of this shift. This expected change in the general passengers' visual landscape adds to the importance of further research on the subject of carsickness.

5. Acknowledgement

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6. References

Bardy, B.G., Warren, W.H., Kay, B.A., 1999. The role of central and peripheral vision in postural control during walking. *Perception & Psychophysics*, 61(7), 1356–1368.

Begg, D., 2014. A 2050 vision for London: what are the implications of driverless transport. Clear Channel

Bos, J.E., 2004. How motions make people sick such that they perform less: a model based approach. In *RTO AVT Symposium on Habitability of Combat and Transport Vehicles: Noise, Vibration and Motion* (Vol. 110, pp. 1-11).

Bos, J.E., 2015. Less sickness with more motion and/or mental distraction. *Journal of Vestibular Research*, 25(1), 23–33.

Bos J.E., Bles, W., Groen, E.L., 2008. A theory on visually induced motion sickness. *Displays* 29(2), 47-57.

Bos, J.E., MacKinnon, S.N., Patterson, A.. 2005. Motion sickness symptoms in a ship motion simulator: effects of inside, outside, and no view. *Aviation, Space, and Environmental Medicine*, 76(12), 1111-1118.

Bos, J. E., de Vries, S. C., van Emmerik, M. L., & Groen, E. L. (2010). The effect of internal and external fields of view on visually induced motion sickness. *Applied Ergonomics*, 41(4), 516–521.

Bles, W., Bos, J.E., de Graaf, B., Groen, E., Wertheim, A.H., 1998. Motion sickness: only one provocative conflict? *Brain Research Bulletin*, 47(5), 481–487.

Chen, Y.C., Dong, X., Chen, F.C., Stoffregen, T.A., 2012) Control of a virtual avatar influences postural activity and motion sickness. *Ecological Psychology*, 24, 279-299.

Dichgans J., Brandt T., 1978. Visual-vestibular interaction: Effects on self-motion perception and postural control. In Held R., Leibowitz H.W., Teuber H.L. (eds) *Perception* (pp. 755–804), Berlin, Germany: Springer.

Diels, C., 2014. Will autonomous vehicles make us sick. *Contemporary Ergonomics and Human Factors*, 301-307.

Diels, C., Bos, J.E., 2015. User interface considerations to prevent self-driving carsickness. In *Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 14-19). ACM.

Diels, C., Bos, J.E., 2016. Self-driving carsickness. *Applied Ergonomics*, 53, 374–382.

Diels, C., Bos, J.E., Hottelart, K., Reilhac, P., 2016. Motion Sickness in Automated Vehicles: The Elephant in the Room. In *Road Vehicle Automation* 3 (pp. 121-129). Springer International Publishing.

Dong, X., Yoshida, K., Stoffregen, T.A., 2011. Control of a virtual vehicle influences postural activity and motion sickness. *Journal of Experimental Psychology: Applied*, 17, 128-138.Griffin, M.J., Newman, M.M., 2004. Visual field effects on motion sickness in cars. *Aviation, Space, and Environmental Medicine*, 75(9), 739–748.

Feenstra, P.J., Bos, J. E., van Gent, R.N., 2011. A visual display enhancing comfort by counteracting airsickness. *Displays*, 32(4), 194-200.

ISO14198, 2012. Road vehicles - Ergonomic aspects of transport information and control systems - Calibration tasks for methods which asses driver demand due to the use of in-vehicle systems. ISO/TS 14198:2012(en).Kato, K., Kitazaki, S., 2008. Improvement of ease of viewing images on an in-vehicle display and reduction of carsickness (No. 2008-01-0565). SAE Technical Paper.

Kennedy, R. S., Drexler, J., Kennedy, R.C., 2010. Research in visually induced motion sickness. *Applied ergonomics*, 41(4), 494-503.

Keshavarz, B., Hecht, H., 2014. Pleasant music as a countermeasure against visually induced motion sickness. *Applied ergonomics*, 45(3), 521-527.

Keshavarz, B., Riecke, B.E., Hettinger, L.J., Campos, J.L., 2015. Vection and visually induced motion sickness: how are they related? *Frontiers in Psychology*, 6, 1–11.

Litman, T., 2014. Autonomous vehicle implementation predictions. Victoria Transport Policy Institute.

Miksch, M., Steiner, M., Miksch, M., Meschtscherjakov, A., 2016. Motion Sickness Prevention System (MSPS): Reading Between the Lines. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct* (pp. 147-152). ACM.

Money, K. E., 1970. Motion sickness. *Physiological Reviews*, 50(1), 1–39.

McKenzie, B., 2015. Who Drives to Work? Commuting by Automobile in the United States: 2013. American Community Survey Reports. Washington, DC: US Bureau of the Census.

McCauley, M.E., Royal, J.W., Wylie, C.D., O'Hanlon, J.F. Mackie, R.R., 1976. Motion sickness incidence: exploratory studies of habituation, pitch and roll, and the refinement of a mathematical model. Technical Report 1733-2, Goleta, CA: Human Factors Research Inc.

O'Hanlon, J.F., McCauley, M.E., 1974. Motion sickness incidence as a function of the frequency and acceleration of vertical sinusoidal motion. *Aerospace Medicine*, 45(4), 366–369.

Palmisano, S., Allison, R.S., Schira, M.M., Barry, R.J., 2015. Future challenges for vection research: definitions, functional significance, measures, and neural bases. *Frontiers in Psychology*, 6, 193.

Probst, T., Krafczyk, S., Büchele, W., Brandt, T., 1982. Visuelle prävention der Bewegungskrankheit im Auto. *Archiv Für Psychiatrie Und Nervenkrankheiten*, 231(5), 409–421.

Perrin, P., Lion, A., Bosser, G., Gauchard, G., Meistelman, C., 2013. Motion Sickness in Rally Car Co-Drivers. *Aviation, Space, and Environmental Medicine*, 84(5), 473–477.

Reason, J.T., Brand, J.J., 1975. Motion Sickness. Academic Press, London, New York, San Francisco.

Reilhac, P., Millett, N., Hottelart, K., 2016. Shifting Paradigms and Conceptual Frameworks for Automated Driving. In *Road Vehicle Automation 3* (pp. 73-89). Springer International Publishing.

Riccio, G. E., Stoffregen, T.A., 1991. An ecological theory of motion sickness and postural instability. *Ecological Psychology*, 3(3), 195–240.

Rolnick, A., Bles, W., 1989. Performance and well-being under tilting conditions: the effects of visual reference and artificial horizon. *Aviation, Space, and Environmental Medicine*, 60(8), 779-785.

Rolnick, A., Lubow, R.E., 1991. Why is the driver rarely motion sick? The role of controllability in motion sickness. *Ergonomics*, 34(7), 867–879.

R Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

SAE, 2014. Taxonomy and Definitions for Terms Related to on-road Motor Vehicle Automated Driving Systems, J3016.

Sivak, M., Schoettle, B., 2015. Motion sickness in self-driving vehicles. Technical Report No. UMTRI-2015-12, Ann Arbor: University of Michigan Transportation Research Institute.

So, R. H. Y., Ujike, H., 2010. Visually induced motion sickness, visual stress and photosensitive epileptic seizures: What do they have in common? – Preface to the special issue. *Applied Ergonomics*, 41(4), 491–493.

Stern, R.M., Hu, S., Anderson, R B., Leibowitz, H.W., Koch, K.L., 1990. The effects of fixation and restricted visual field on vection-induced motion sickness. *Aviation, Space, and Environmental Medicine*, 61(8), 712.

Turner, M., Griffin, M.J., 1999. Motion sickness in public road transport: passenger behaviour and susceptibility. *Ergonomics*, 42(3), 444–461.

Vlakveld, W.P., 2016. Transition of control in highly automated vehicles: a literature review. The Hague, SWOV Institute for Road Safety Research.

Warren, W.H., Kurtz, K.J., 1992. The role of central and peripheral vision in perceiving the direction of self-motion. *Perception & Psychophysics*, 51(5), 443–454.

Webb, N.A., & Griffin, M.J., 2003. Eye movement, vection, and motion sickness with foveal and peripheral vision. *Aviation, Space, and Environmental Medicine*, 74(6), 622-625.

Wada, T., & Yoshida, K., 2016. Effect of passengers' active head tilt and opening/closure of eyes on motion sickness in lateral acceleration environment of cars. *Ergonomics*, 59(8), 1050-1059.